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ν_μ-ν_e Universality in Charged-Current Neutrino Interactions

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ABSTRACT

Approximately 2000 ν_e and $\bar{\nu}_e$ charged-current interactions with energies ranging up to 200 GeV were observed in a wide band neutrino beam using the Fermilab 15-ft bubble chamber filled with a heavy Ne-H_2 mix. The cross-section, kinematic distributions, charged particle multiplicity, strange particle production, and dilepton production for these events are compared to those for samples of ν_μ and $\bar{\nu}_\mu$ charged-current events obtained during the same experiment. No evidence for a violation of ν_μ-ν_e universality is observed.

The universality of charged leptons has a strong experimental foundation. However, the universality of neutrinos is not as well established. We report on a detailed study of ν_μ-ν_e universality, including comparisons of cross sections and many properties, such as kinematic distributions and the strange particle production rates. These results represent an order of magnitude improvement in statistics over previous bubble chamber studies[1] of neutrino universality. Counter experiments have measured cross sections only.[2]

MASTER

The data used in this study consisted of approximately 360,000 photographs taken in the 15-ft bubble chamber at Fermilab. The experiment, designated as E53, consisted of exposing the bubble chamber to a wide band, horn-focussed neutrino beam generated by 400 GeV protons. The bubble chamber was filled with a Ne-H_2 (64-36 atomic percent) mixture. The experiment was divided into two runs. Both runs combined yielded approximately 160,000 ν_μ charged-current events inside the fiducial volume, with an energy spectrum peaking at 20 GeV and extending up to 200 GeV.

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Each photograph was scanned for events with an e^- or e^+ coming from the vertex. The $e^-(e^+)$ tracks were easily identified in the heavy Ne-H_2 fill. 1403 e^- and 179 e^+ events were found after making an $e^\pm$ momentum cut of 2 GeV/c and removing e^+ events with a leaving negative track, i.e., a μ^-. Backgrounds due to asymmetric gamma conversions and Dalitz pairs, Compton electrons, and K_{e3} decays were estimated to give less than 17±3 events. After making further cuts and correcting for acceptance and efficiencies there were 2196±148 e^- events and 336±34 e^+ events in the total sample. These categories were interpreted as ν_e and $\bar{\nu}_e$ charged-current interactions, respectively. The normalization samples of ν_μ and $\bar{\nu}_\mu$ charged-current interactions were derived from a sample of neutral particle induced events recorded during a scan of an unbiased subset of 1.3% of the total film. Reference 3 provides further details.

The incident fluxes for the various types of neutrinos in this experiment were calculated using a Monte Carlo computer program. The π and K production formula used in this program was given by Malensek.[4] These fluxes, the world average ν_μ charged-current cross section[5], and the measured ν_e, $\bar{\nu}_e$ and ν_μ event rates were used to derive $\sigma(\nu_e)/\sigma(\nu_\mu) = 1.03\pm0.19$ and $\sigma(\bar{\nu}_e)/\sigma(\bar{\nu}_\mu) = 1.50\pm0.35$. Only the first of the two runs for this experiment was used for this result because there was evidence of horn-focussing problems in the second run. These do not affect any of the other results presented here.

As a second test of neutrino universality, the kinematic distributions for the ν_e and $\bar{\nu}_e$ events were compared to those expected from ν_μ and $\bar{\nu}_\mu$ interactions assuming universality. The expected distributions were created from a large number of events generated by a package of Monte Carlo computer programs. These events were weighted by the $\nu_e(\bar{\nu}_e)$ spectrum from the beam Monte Carlo and $\sigma(x,y)/E$ for $\nu_\mu(\bar{\nu}_\mu)$ charged-current interactions.[6] In addition, the $e^\pm$ momentum was smeared using EGS4.[7] The comparisons between the data and the expected distributions are shown in Figures 1-6. The hadronic energy in the data has been corrected for missing neutral energy using a method developed in a narrow band beam.[8] The errors shown for the data are statistical

only. The 1σ boundary lines are shown for the Monte Carlo distributions. The error in the Monte Carlo includes a 10% error in the ν_μ $\sigma(x,y)/E$ parameterization, a 15% error in the $\nu_e(\bar{\nu}_e)$ energy spectrum from the beam Monte Carlo, and a 15% to 20% error in the hadronic energy.

The average charged particle multiplicity as a function of the square of the invariant mass of the charged hadrons is shown in Figure 7 for the ν_e and ν_μ samples. The corresponding plot for antineutrinos is shown in Figure 8.

A search for neutral strange particle decays yielded (after cuts) 109 vees and 7 vees in the ν_e and $\bar{\nu}_e$ interactions, respectively. After correcting for acceptance and efficiencies the observed rates for neutral strange particle production were

$$\frac{\nu_e N \to e^- V^o X}{\nu_e N \to e^- X} = (11.7\pm1.2)\% \quad \text{and} \quad \frac{\bar{\nu}_e N \to e^+ V^o X}{\bar{\nu}_e N \to e^+ X} = (5.2\pm2.2)\% \ .$$

The comparable rates for ν_μ and $\bar{\nu}_\mu$ interactions are $(9.8\pm0.7)\%$[9] and $(7.3\pm0.7)\%$[10], respectively.

Finally, a search was conducted for e^-e^+ dilepton events. These events are expected to arise from ν_e-induced charm production and subsequent semileptonic decay. Examples of events consistent with this process have been observed previously.[11] However, no rate has been reported for this process. The e^-e^+ candidates were required to have $P_{e^-}>5$ GeV, $P_{e^+}>1$ GeV, and no μ^-. In addition, the square of the invariant mass of the e^-e^+ system was required to be greater than 0.16 GeV^2. This search yielded 7 events with 2 vees and an estimated background of 0.7±0.7 events. After correcting for acceptance and efficiencies these numbers yielded the following rates:

$$\frac{\nu_e N \to e^- e^+ X}{\nu_e N \to e^- X} = (0.79\pm0.35)\% \text{ and } \frac{\nu_e N \to e^- e^+ V^o X}{\nu_e N \to e^- e^+ X} = (0.46\pm0.36).$$

The comparable numbers for ν_μ interactions are $(0.52\pm0.09)\%$ and (0.35 ± 0.05), respectively.[12] There is additional kinematic evidence that these events come from ν_e-induced charm production and decay. The electron momenta are all substantially harder than the positron momenta. Also, as

shown in Figures 9a-c, the opening angles between the transverse momenta of the hadronic system, the electron, and the positron are consistent with the electron being produced away from the hadrons and the positron being produced as part of the hadronic shower.

In conclusion, a number of different tests of neutrino universality have been conducted with an order of magnitude more statistics than used in previous experiments of this type. No significant evidence for a violation of neutrino universality is seen. Also, the first rate for a ν_e-induced (e^-e^+) dilepton signal is reported.

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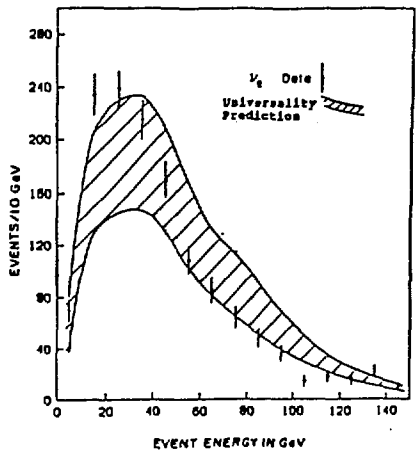


Figure 1

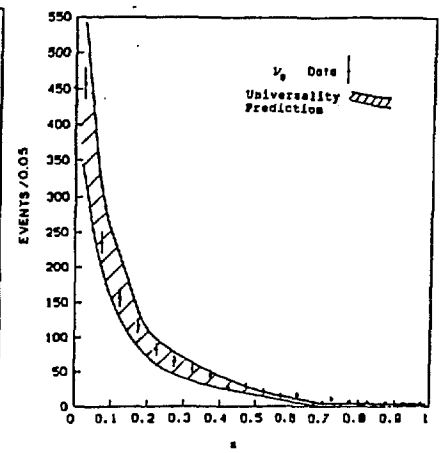
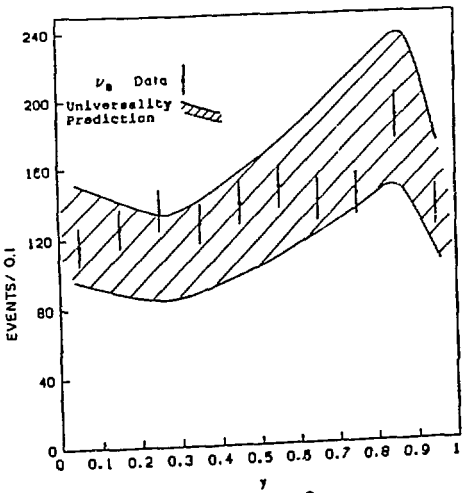


Figure 2

*Supported in part by the U.S. Dept. of Energy under Contract DE-AC02-76CH00016.



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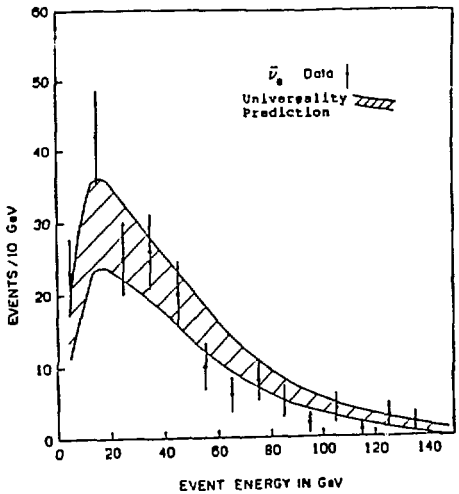
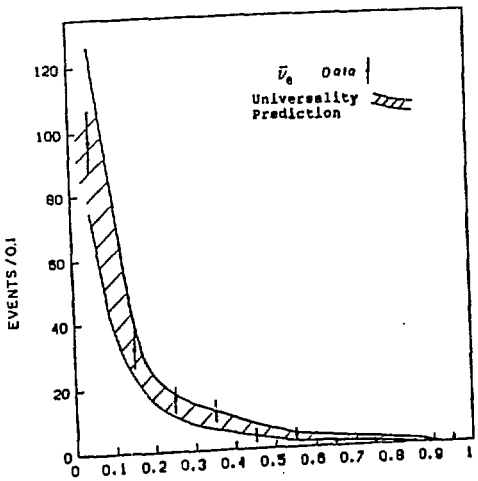


Figure 4



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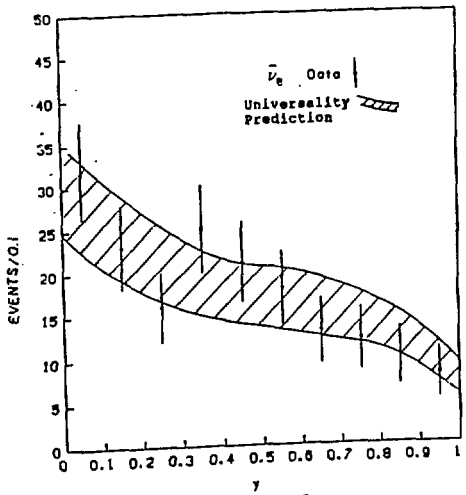

Figure 6

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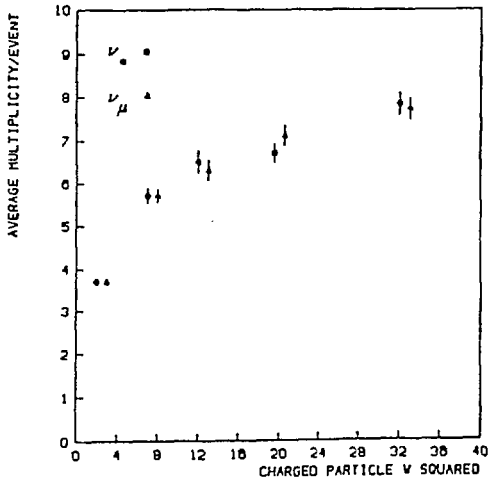
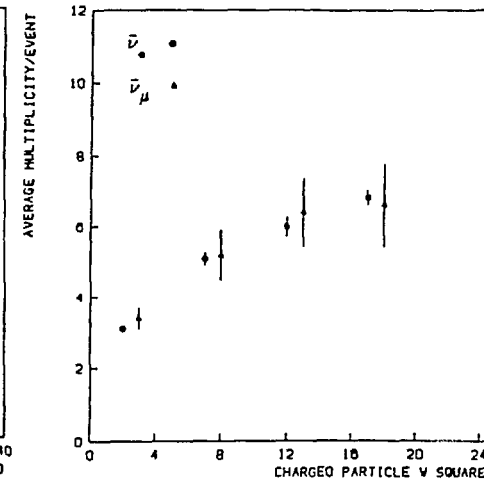


NEUTRINOS

Figure 7



ANTINEUTRINOS

Figure 8

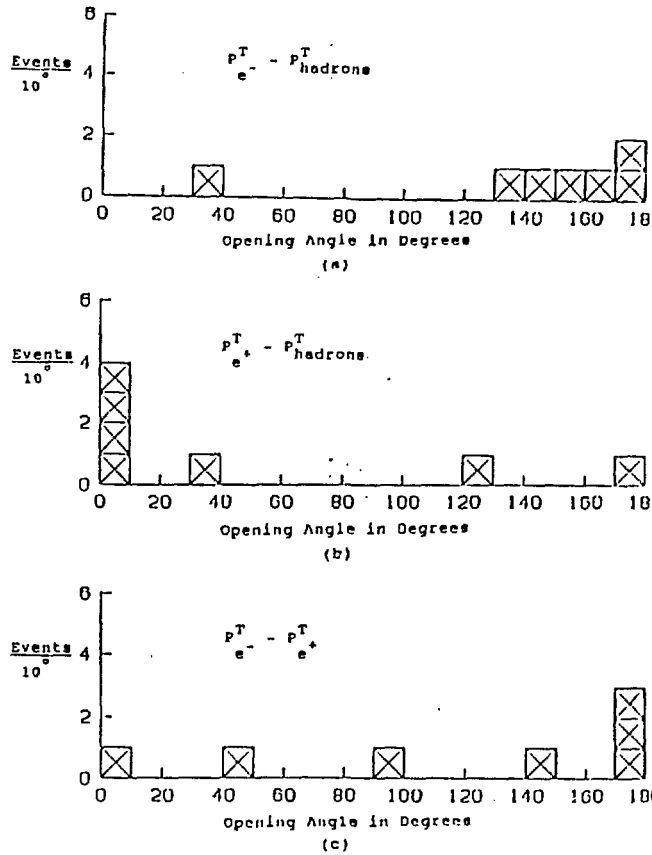


Figure 9